Vector Sensor Antenna System (VSAS)

- **Team**
  - **SoneSys:** Lou Gargasz, Gary Strauch, Dr. Harvey Woodsum
    - AOA analysis of candidate VSAS configurations to allow downselection
    - System testing
    - Comparison of VSAS performance with monopole array
  - **MegaWave**: Marshall Cross, Glynda Benham
    - VSAS design
    - Modeling and manifold computation

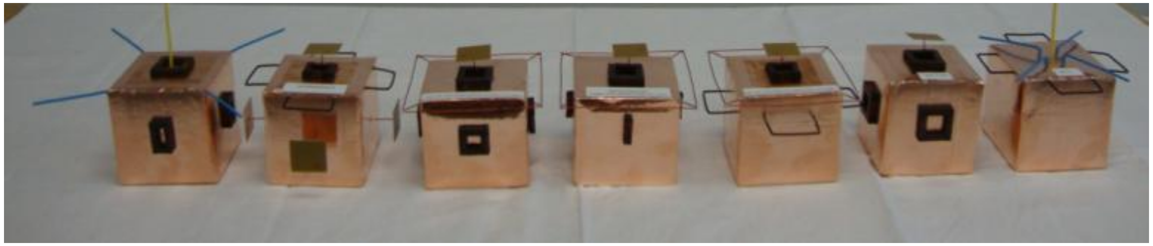
Phase 1a VSAS Performance GOALS

- 5-10 MHz
- < 0.8° AZ. and EL. AOA Error @ 30 dB SNR
- < 20 dB NF @ 8 MHz
- > 20 dB polarization isolation
- Fully polarimetric
- > -5dBi Total Gain Over ½ Space (Sum)
- Footprint: single element or building block

  < 40 meters in any dimension & 15 meters in height

VSAS Design Process

- 7 alternative configurations
  - EM modeling & manifold computation
  - Lab measurements
  - AOA simulations (SoneSys)
  - Mechanical considerations



- 1/6th scale model of best configuration
- Detailed prototype mechanical design and test

Phase 1 VSAS Configuration

"11-D Fractional Wavelength Array"

Box size = 2 m x 2m x 2m

5-Monopoles (1-TM & 4-TE) = 1.5 m

1-TM Picture Frame (NS/EW) =0.36 x 0.36 x 0.1 m

4-TE Picture Frames = 0.36 x 0.21 x 0.1 m

Footprint = 3.78 x 3.78 m (14.3 m^2)

Height = 3.5 m

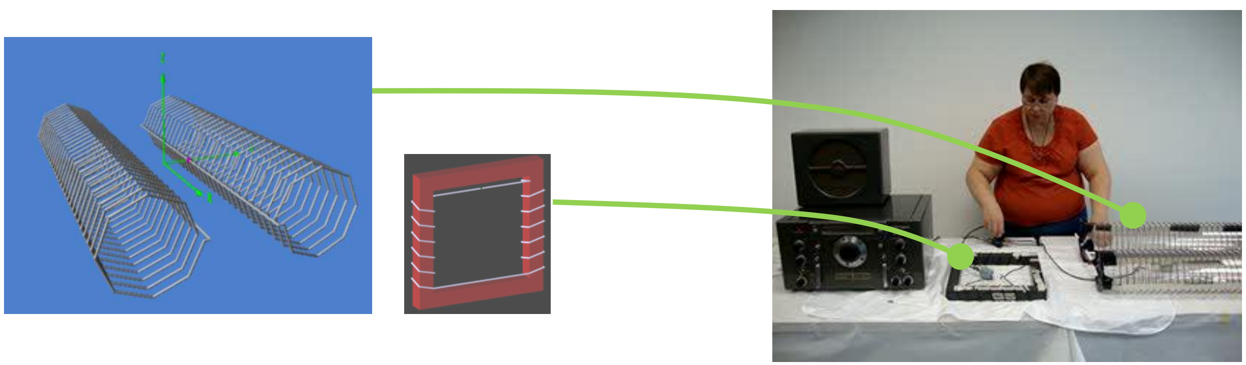
Max. Dimension: 5.34 m (0.178 λ @ 10 MHz)

Vector Sensor Design and Trades - Approach

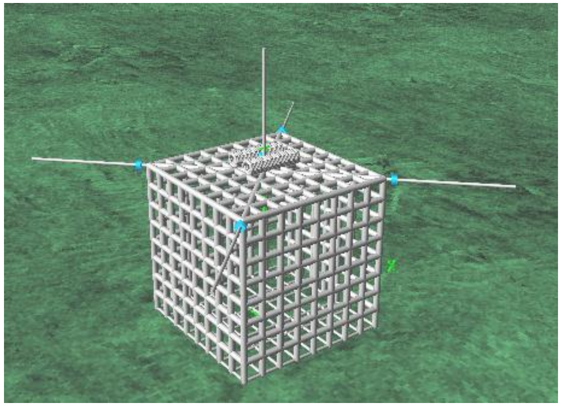
- Candidate configurations defined
- Modeled in 4nec2/NEC4 Moment Method Code
- Compare performance to determine effects of varying design parameters/configuration
  - RX patterns due to linear plane wave
  - Elements terminated in equivalent JFET impedance
  - Compute RX power into real part of JFET from currents
- Trade study parameters
  - Configuration, ground screens, E-field sensor length, sensitivity to ground constants, box size
- Generate manifolds
  - Characterize VSAS response to CP plane wave excitation
  - AOA/polarization separation computation (SoneSys)
- Select best configuration for scale model/full scale fabrication/test

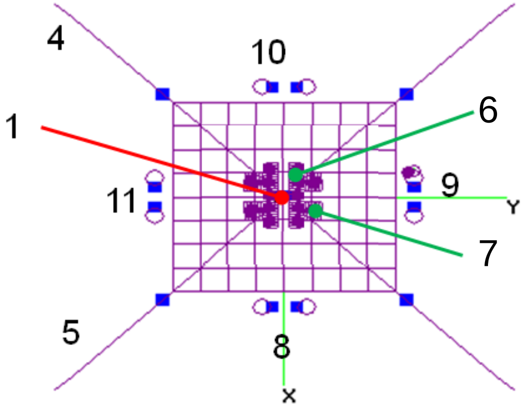
Picture Frame Modeling

- Manifold best generated using NEC-4.2
  - Handles plane wave illumination
  - Angle of incidence over full hemisphere can be incremented in single run
  - Includes infinite real earth
  - Reasonable computation time
- NEC cannot directly model ferrite-loaded picture frames
- Equivalent air core loop approach developed
- Equivalence verified experimentally
- Received signal from locally generated 8MHz signal measured on HRO 60
- Same signal levels and audio quality on NEC air loops and PF with CHU Canada (7.85MHz)



VSAS – Receive Patterns

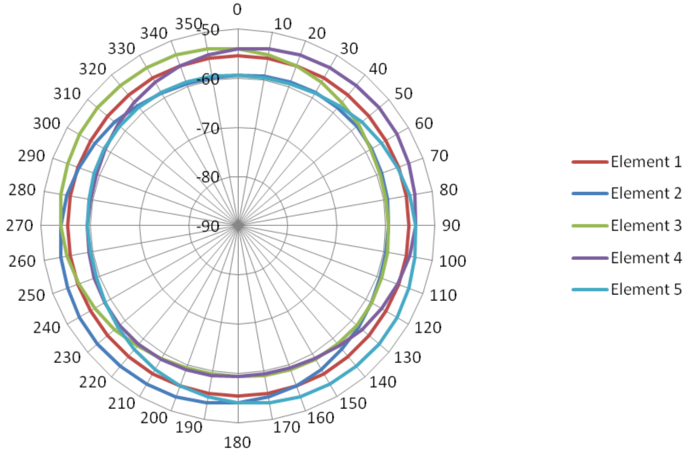




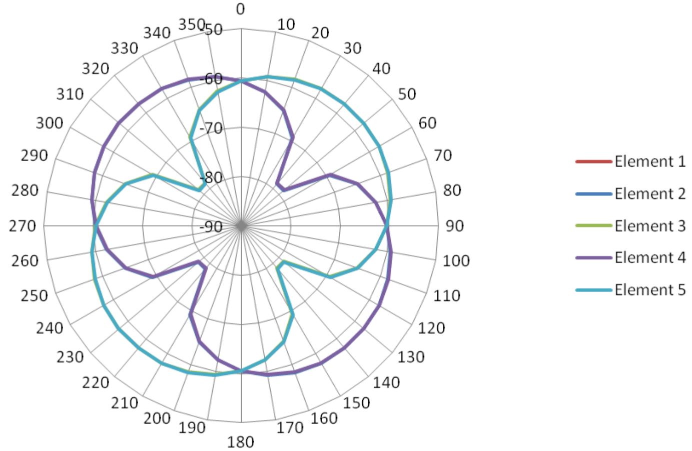
Element Numbers

1: Vertical monopole
2-5: Horizontal monopoles
6-7: Top picture frame (x and y windings)
8-11: Side picture frames

Power into JFET Load Due to E_θ Plane Wave
E-field Elements, Real Earth, L_E=1.5m
Azimuthal Receive Pattern for θ=40 degs



Power into JFET Load Due to E_ϕ Plane Wave
E-field Elements, Real Earth, L_E=1.5m
Azimuthal Receive Pattern for θ=40 degs

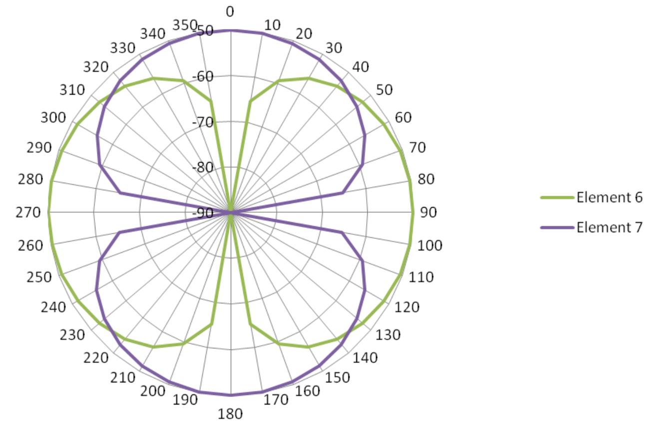


Monopoles

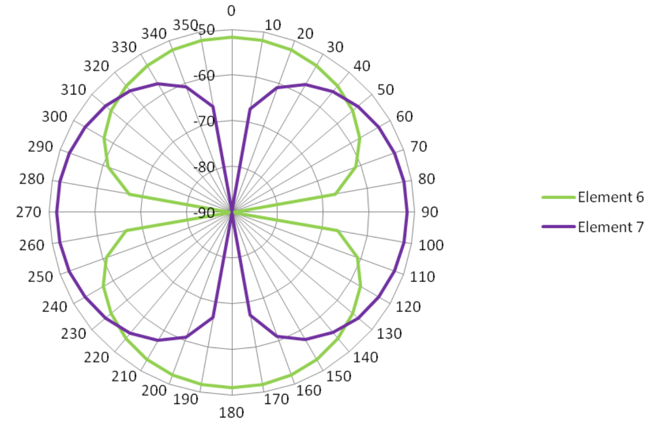
Top and Side Picture Frames – Receive Patterns

Top picture frame

Power into JFET Load Due to E_θ Plane Wave
Square Picture Frame, Real Earth, L_E=1.5m
Azimuthal Receive Pattern for θ=40 degs

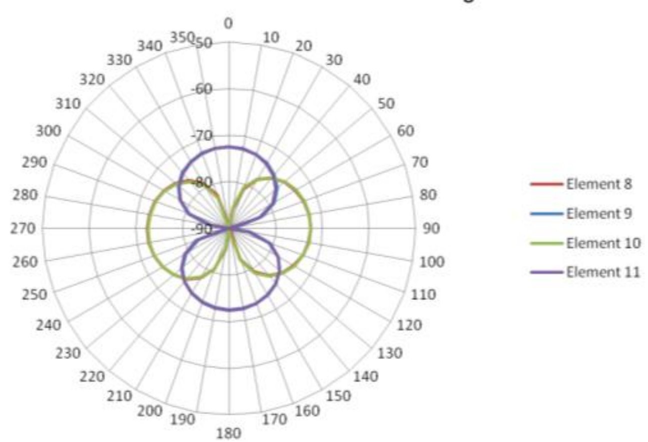


Power into JFET Load Due to E_ϕ Plane Wave
Square Picture Frame, Real Earth, L_E=1.5m
Azimuthal Receive Pattern for θ=40 degs

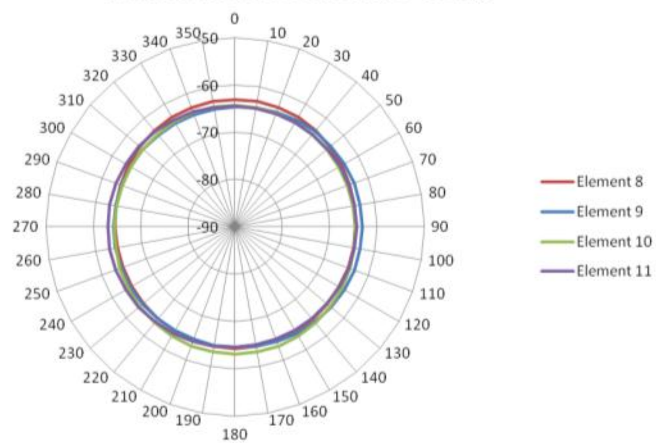


Side picture frames

Power into JFET Load Due to E_θ Plane Wave
Rectangular Side Face Picture Frame, Real Earth, L_E=1.5m
Azimuthal Receive Pattern for θ=40 degs

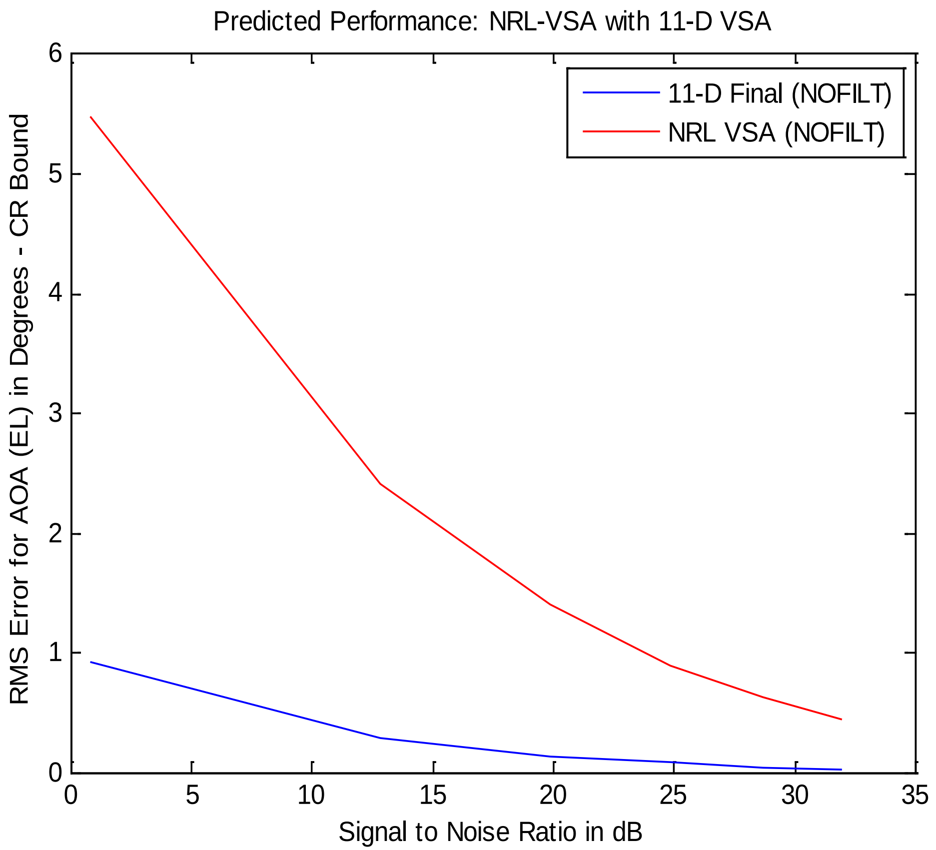


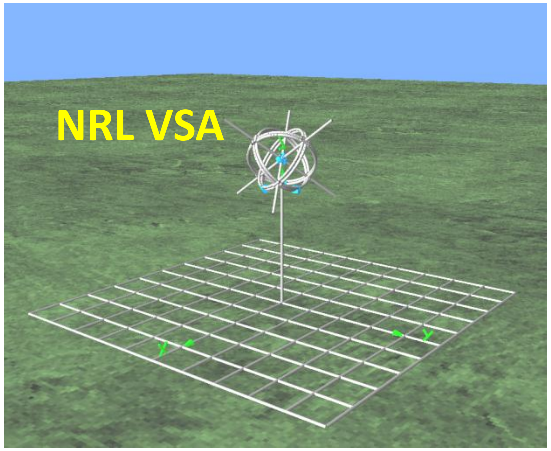
Power into JFET Load Due to E_ϕ Plane Wave
Rectangular Side Face Picture Frame, Real Earth, L_E=1.5m
Azimuthal Receive Pattern for θ=40 degs



AOA Comparison

- **Manifold data computed for RHCP & LHCP incident plane waves**
- **AOA computed used Dr. Woodsum algorithm**
- **AOA for VSAS configurations compared to NRL VSA**
- **Final Phase 1A 11D VSAS has significantly better performance than NRL VSA**





- 6D
- 3 dipoles, 3 loops
- Size:
  - 4.8m x 4.8m ground screen
  - 2.6m high

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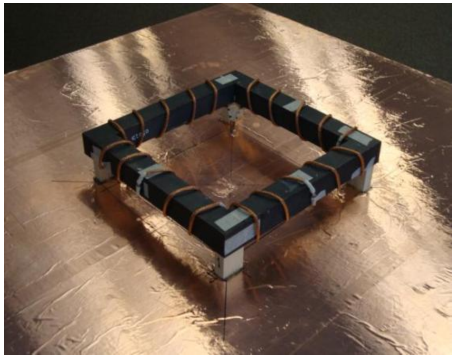
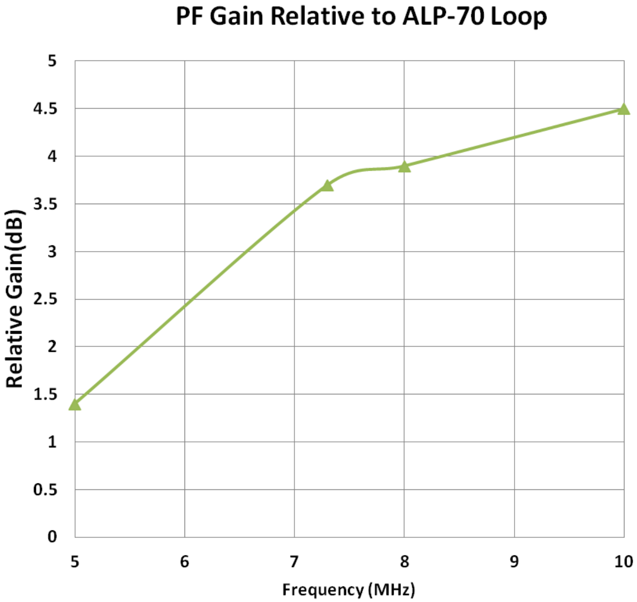
Picture Frame (PF) Loops

- **Proven for VLF, LF and MF**
  - VSAS is first implementation at HF
- **Pros**
  - Low Profile/compact
  - Low winding inductance
  - Low distributed capacitance
  - Sensitivity and NF > 1 m dia air loop
  - N-S/E-W isolation ≈ 40 dB (also TM-TE)
  - ≈50 dB near-E shielding
- **Cons**
  - Heavy ≈ 20 lbs.
  - Time consuming/challenging EM simulations



12" square PF

1m dia reference air loop



VSAS Measured Performance: Bedford, NH

- "Sensitivity"
  - Local 200mW TM/TE beacon
  - ALP-70 reference loop
  - Subtracted VSAS measured amplifier gains
  - Δ dB:

VSAS Antenna	4.915 MHz	8.002 MHz	10.181 MHz
TM Loop	11.8	10.9	18.8
TE Loop	14.4	16.7	18.4
TM Monopole	9.1	10.2	12.2
TE Monopole	17.7	12.0	7.6

Conclusion: Picture Frame ~12 to 19dB more sensitive than 1m diameter air-core loop

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VSAS Measured Performance: Bedford, NH

- "SNR"
  - Local 200mW TM/TE beacon
  - ALP-70 reference loop
  - Noise: ≈ 1800 UTC, July, 3 kHz b.w. (MM+Cos.+Atmos.+ VSAS)
  - Δ dB:

VSAS Antenna	4.9152 MHz	8.002 MHz	10.181 MHz
TM Loop	3.3	8.7	10.7
TE Loop	5.3	9.1	13.5
TM Monopole	7.4	12.4	13.3
TE Monopole	17.8	16.2	6.0

- **Conclusion: PF provides ~3 to 13dB SNR improvement over 1m dia air-core loop**

PF Noise Figure Estimation

- Goal <20dB @ 8MHz
- NF cannot be measured outside due to external noise exceeding target NF
  - Requires large shielded anechoic chamber
- NF estimated from Hermes loop (Miron, 2006) and measured relative surface wave gain of PF loops and air loop

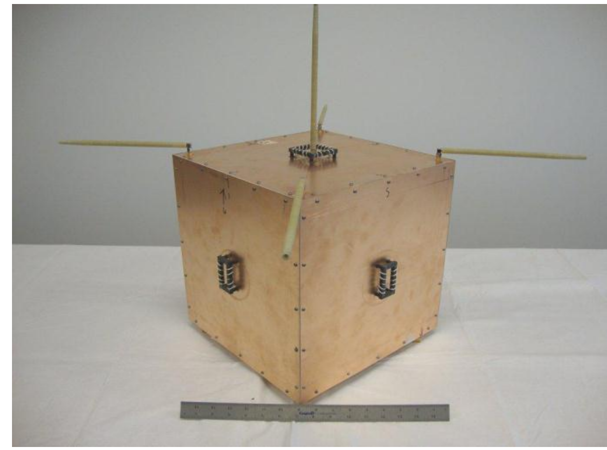
	5MHz	8MHz	10MHz
Hermes Loop NF, dB (Miron)	33.1	27.3	25
PF gain relative to 1 m air loop, dB	3.4	4.3	4.6
Estimated PF NF, dB	**29.7**	**24**	**20.4**

- Conclusion: PF NF slightly higher than program goal

SoneSys MegaWave CORPORATION

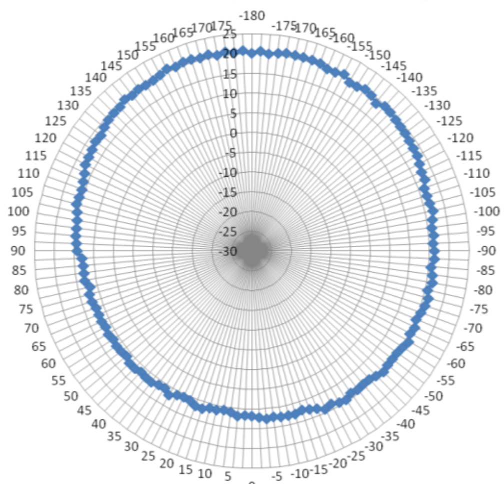
1/6th VSAS Scale Model: 30-60 MHz

- **Rationale**
  - Paucity of HF Ranges
  - Check on NEC-4.2
  - Convenient for lab measurements
  - Interference
- **EPG Arc Range, Fort Huachuca**
- **Measured isolation 30-90dB**

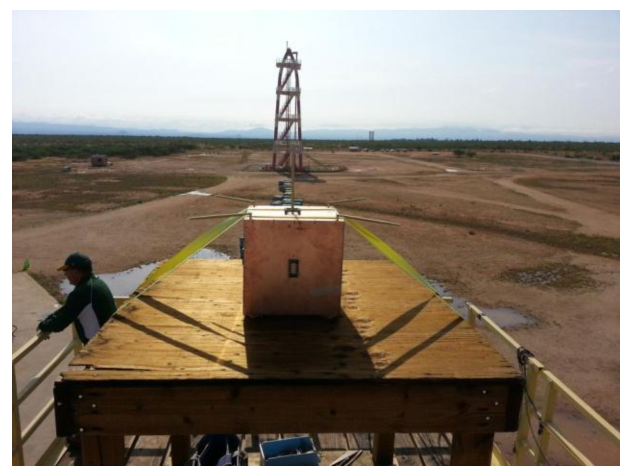


1/6th scale model

Vertical Whip, Vert Pol., 50 deg. Elev.



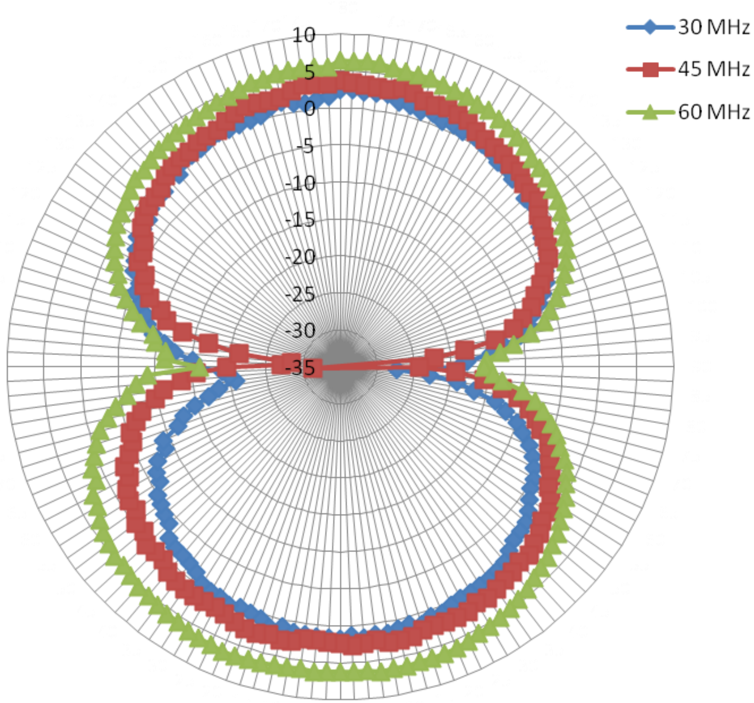
Vertical monopole – measured azimuth pattern



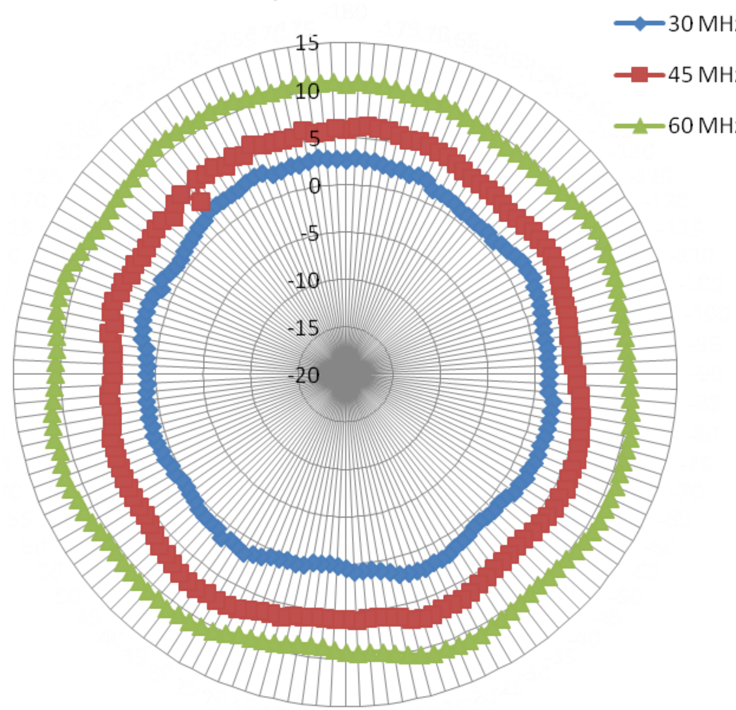
EPG Arc Range Test Setup

1/6th Picture Frame Loop Patterns

Picture Frame on Top of Box
(N-S), V-Pol, 20^{o} Elevation



Picture Frame on North Side of Box,
H-Pol, 50^{o} Elevation



- **Scale model measurements confirmed:**
  - **Nominally omni pattern of vertical monopole (unexplained measurement variation)**
  - **Figure-eight patterns of upper PF**
  - **Nominally omni patterns of side face PF**

Phase 1A Key Achievements

- Met or exceeded all Phase 1A goals
- Validated PF as a sensor element for the VSAS
- Equivalent model for PF's allowed efficient computation of manifolds
- Picture frame loops vs. 1 m dia air Loop
  - Reduced profile
  - ~12 to 19dB greater sensitivity
  - ~3 to 13dB better SNR
  - Estimated NF exceeded program goals

HFGeo VSAS
Testing and Results

SoneSys HFDF Test Range

- 3.6 acres near Manchester (MHT) airport
- Cabling via underground conduit
- Worldwide remote access via the Internet

- Power
- DSL Line
- RF cables

VSAS Installation

Test Configuration

Remotely controlled:

- **Wideband HF tuners (12)**
- **Up to 48 narrowband outputs**
- **I&Q coherent recording**
- **Playback of recorded files**
- **Antenna switch matrix (12x2)**

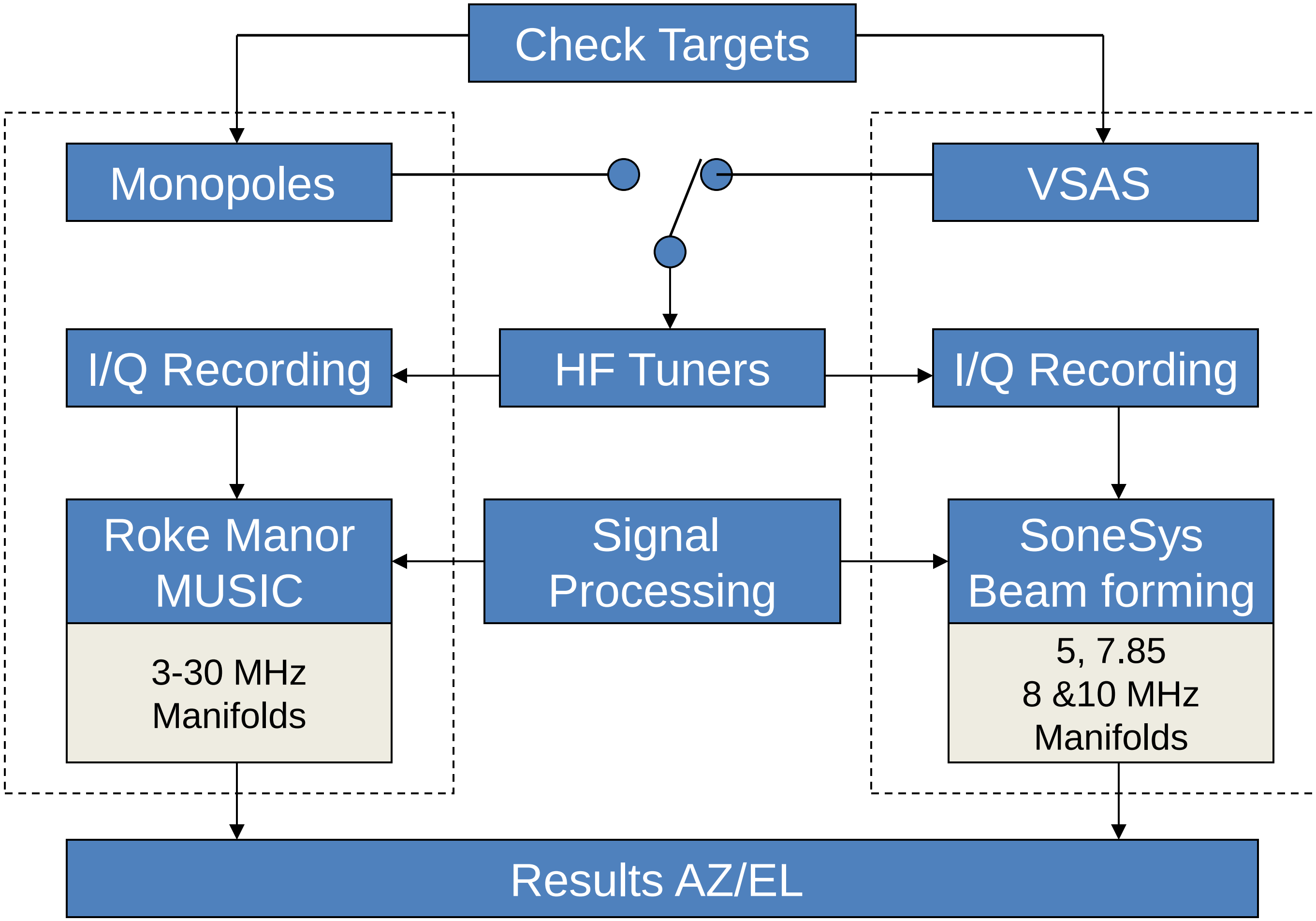
Large Baseline Array

- **75M circular array (28ft whips)**
- **8 Channel Superresolution DF**
- **MUSIC Algorithm**

VSAS

- **2 Meter^3**
- **11 channel Superresolution DF**
- **Digital Beamformer Algorithm**

HFGeo Testing Methodology



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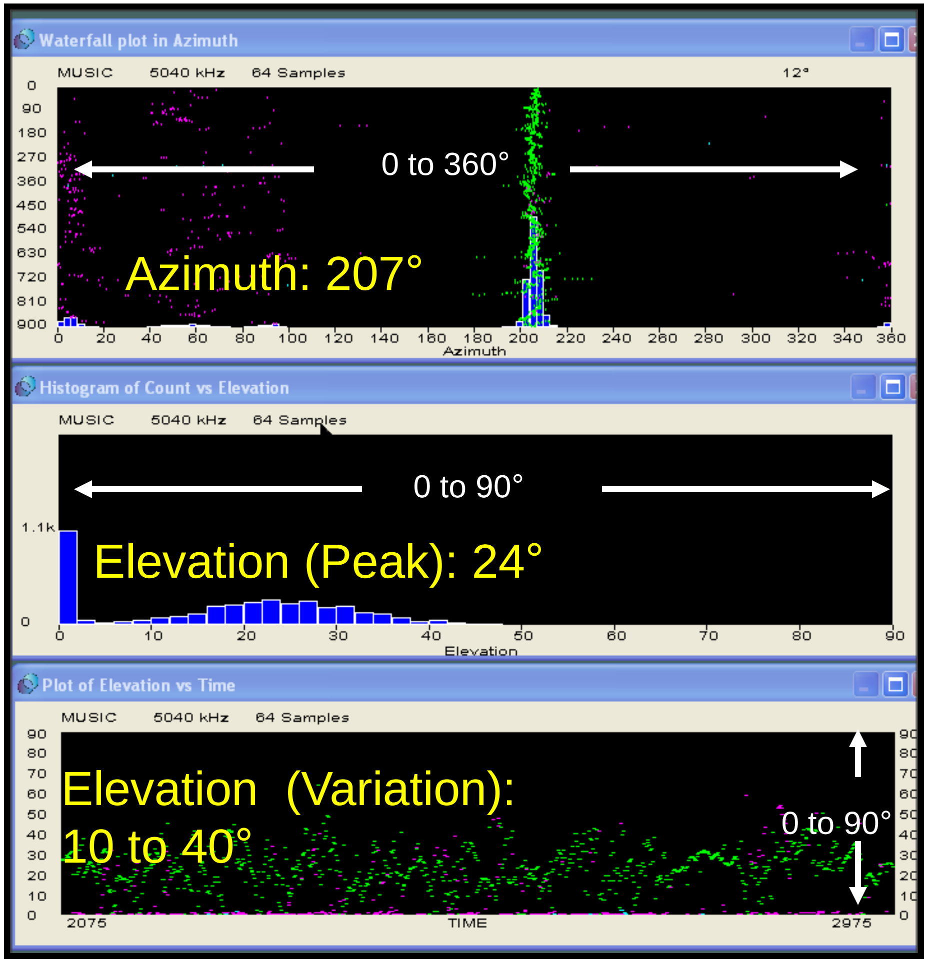
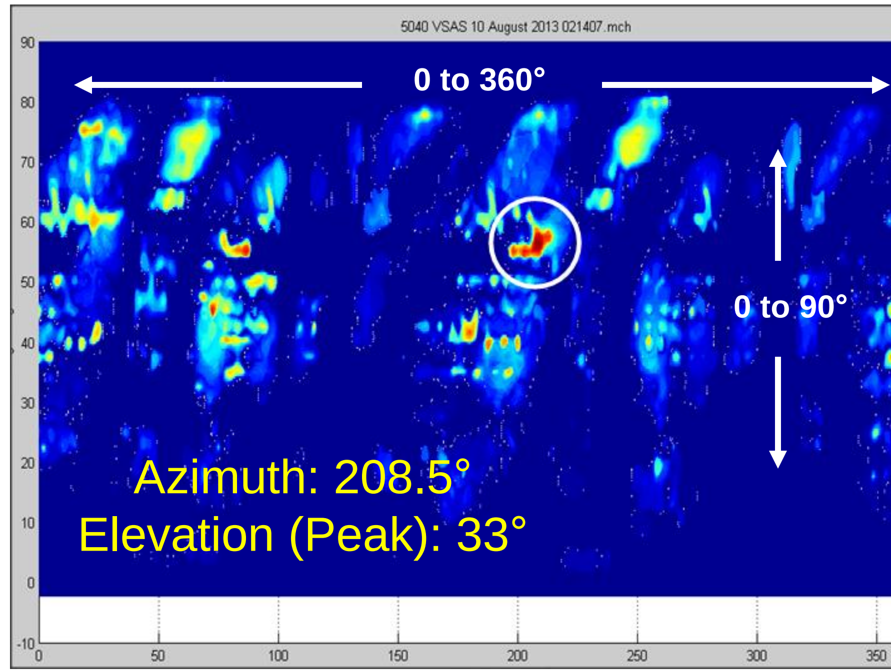
Data Example

Monopole Array @ 02:11Z



VSAS Array @ 02:14Z



Example:

5040 KHz Aug 10, 2013

Havana Cuba @ 207.5°

SNR ≈ 23db

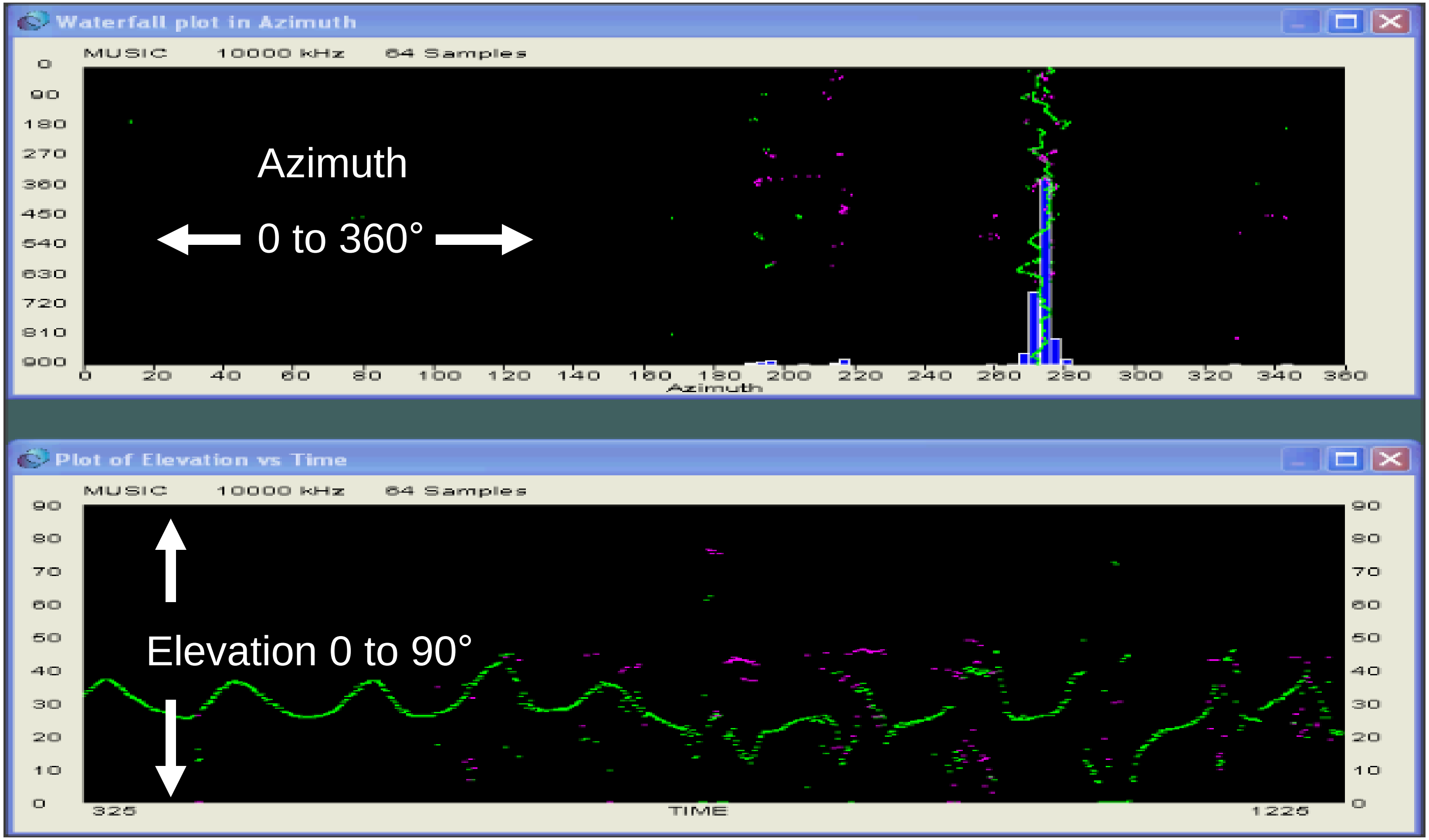
Comparative Results

Freq (Khz)	Call Sign	Transmitter Location	Lat Decimal	Long Decimal	Range (KM)	TRUE AZ	75 Meter Array Az	75 Meter Array EL	VSAS Az	VSAS EL	Azimuthal Error 75 M	Azimuthal Error VSAS
		5 MHz Manifold										
5000	W W V	Boulder CO (Time)	40.6797	-105.041	2776	276.4	275	23	275	46	1.4	1.4
5040	Havana	Havana Cuba	22.8233	-82.293	2448	207.5	207	24	208.5	33.5	0.5	-1.0
5050	WWRB	Morrison TN	35.6241	-86.0144	1489	241.8	242	41	243	32	-0.2	-1.2
5097	CFH	Halifax	44.9675	-63.985	640	66.6	67	8	65	14	-0.4	1.6
		7.85 MHz Manifold										
7850	CHU	Ottawa Canada (Time)	45.2964	-75.7561	432.5	309.2	310	51	309.5	30	-0.8	-0.3
		8 MHz Manifold										
8040	GYA	Northwood UK	51.6194	0.4094	5281	53.1	51	15	51	23.6	2.1	2.1
		10 MHz Manifold										
9980	WWCR	Nashville TN	36.208	-86.894	1526	245.7	246	29	246	16	-0.3	-0.3
10000	WWV	Boulder CO (Time)	40.6797	-105.041	2776	276.4	276	25	277	44	0.4	-0.6
10051	WSY70	New York (VOLMET)	39.749	-74.39	429	215.7	215	27	216	29	0.7	-0.3
10051	VFG	Gander NFL (VOMET)	48.968	-54.824	1447	56.6	56	27	56.5	15.8	0.6	0.1
10101	DDK9	Hamburg Germany	53.6627	9.795	5927	47.01	47	31	48.1	15.2	0.0	-1.1
										RMS	**0.88**	**1.09**

Range Testing

- Results
  - “Out of the Box with no tweaks”
    - →Theoretical Manifold with no calibration
    - →First of a kind manifold (picture frames)
    - →Pre-amp transfer functions not included
    - →SoneSys DF processing technique
    - →Single digit azimuthal errors
- 75 meter array vs. 2 meter array (VSAS)
  - Comparable accuracy
- Single site geolocation highly dependent on short term fluctuations induced by the ionosphere

Ionospheric Observations



10 MHz varying EL.avi

Sample Recordings

- 10.051 MHz Upper Sideband

  - New York VOLMET.avi
  - 8/14/13 @ 13:34Z
  - Stable Ionosphere

  - Gander VOLMET.avi
  - 8/14/13 @ 13:22Z
  - Varying Ionosphere

Conclusions

- Initial results indicate VSAS azimuthal AOA error $\approx$ as 75 meter 8-element monopole array
- Results highly dependent on good manifold data
  - Estimate manifolds required every 0.5 MHz
  - Additional modeling refinements to improve accuracy
- Ionosphere appears to be dominant source of elevation AOA error on skywave signals

Phase 2 Suggested Tasks

- **PF design: extend frequency coverage to 3-30MHz**
- **VSAS ground/earthing system optimization**
  - Stabilize VSAS AOA accuracy and provides better lightning protection
- **Manifolds**
  - Derive method for including surfacewave component
- **Mechanical**
  - Reduce weight and improve robustness using novel materials for PFs
  - Review overall VSAS construction and materials
- **Full scale measurement**
  - SSC near field arch
  - Compare with codes
  - Understand computed manifold accuracy and effects of manifold “errors” on AOA
- **NF measurements in shielded anechoic chamber**
- **In-Situ 3-30 MHz σ, ε_r ground probe**

Phase 2 Partnerships

5 key areas identified in Bidders Day Announcement

We offer:

- Electrically small VSAS design, matching, manifold development and testing
- Signal separation

We seek to team with all prime system integrators with expertise in:

- Geolocation
- Propagation mode isolation
- Ionospheric modeling

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